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ABSTRACT

As part of a larger project aimed at exploring how students' conceptual growth results from interacting with the teacher and the assigned readings associated with a course, this study focused on how prospective elementary teachers conceptualized two concepts, evaporation and condensation in a Concepts in Earth Science Course. In the conceptual change literature, very few studies have concentrated on prospective science teachers' knowledge change. There are still fewer studies that have analyzed classroom discourse in any depth. This study analyzed transcriptions of classroom discussion discourse, both students' and teacher's stimulated recall interviews, and follow-up interviews, students' answers to their tests, observation notes, and conceptual profile inventories to discern students' alternative concepts and how students accommodated scientific explanations. The study found that: (1) most students were not clear about heat transformation involved in evaporation and condensation; (2) many of them did not think of evaporation and condensation in terms of molecular movement and energy; (3) few of them integrated their knowledge of heat transformation, molecular movement, energy, and change of states to explain the effect of evaporation and condensation on the surrounding air; and (4) disconnected information provided by textbook and classroom discussion did not help students understand these two concepts. (Author/PR)

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EXAMINING HOW PROSPECTIVE TEACHERS COME TO UNDERSTAND TWO SCIENCE CONSTRUCTS, EVAPORATION AND CONDENSATION, AS A RESULT OF CLASS DISCUSSION AND TEXTBOOK READING

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Abstract

As part of a larger project aimed at exploring how students' conceptual growth results from interacting with the teacher and the assigned readings associated with a course, we focused on how prospective elementary teachers conceptualized two concepts, evaporation and condensation, in a Concepts in Earth Science course. In the conceptual change literature, very few studies (e.g., Arzi, 1987 & 1991) have concentrated on prospective science teachers' knowledge change. There are still fewer studies (e.g., Eaton, Anderson & Smith, 1984) that have analyzed classroom discourse in any depth. In this study, we analyzed transcriptions of classroom discussion discourse, both students' and teacher's stimulated recall interviews, and follow-up interviews, students' answers to their tests, observation notes, and conceptual profile inventories to discern students' alternative concepts and how students accommodated scientific explanations. We found that (1) most students were not clear about heat transformation involved in evaporation and condensation; (2) many of them did not think of evaporation and condensation in terms of molecular movement and energy; (3) few of them integrated their knowledge of heat transformation, molecular movement, energy, and change of states to explain the effect of evaporation and condensation on the surrounding air; and (4) disconnected information provided by textbook and classroom discussion did not help students understand these two concepts.

Introduction

Vygotsky's theory of how language mediates human higher mental functions in both social and individual activity, his ideas about the process of internalization, concept development, and zone of proximal development suggest an approach to describe and explain conceptual development. Vygotsky (1978) defines "internalization" as the internal reconstruction of an external operation. In classroom learning, students' interactions with their teacher, classmates, and textbook influence their conceptualization. The quality of these interactions influence intrapsychological processes and bring the students closer to internalizing a concept. In the data we report here, we focused on the transformation from interpsychological processing into intrapsychological processing in students' understanding of evaporation and condensation before, during, and after classroom discussion.

Method

Vygotsky's microgenetic approach (Vygotsky, 1978; Wertsch, 1985; and Wertsch & Hickmann, 1987) and Glaser and Strauss' (1967) grounded theory were taken as guiding principles for data collection and analysis. The essence of a microgenetic analysis is to capture the turning points in learning when conceptual change occurs. In presenting Vygotsky's microgenetic method, Wertsch (1985) concluded that there are two type of microgenesis. The first type "concerns the short-term formation of a psychological process" and requires "observations of subjects' repeated trials in a task setting." The second type of microgenesis involves "the unfolding of an individual perceptual or conceptual act, often in the course of milliseconds" (Wertsch, 1985, p. 55). Both types serve to describe and explain the process of conceptualization in classroom communicative activity, the first providing a description of conceptual growth over an extended period of time and the second describing conceptualization as it occurs in split of a second, i.e., a student understands a concept when he or she hears a critical term from classroom discussion. The essential purpose in both types is to capture the process of internalization as a result of interaction between intra- and interpsychological mental processing.

In addition, a grounded theory approach was used in data collection and analysis. Following grounded theory (Glaser & Strauss, 1967), the data was analyzed in the early course of data collection. The follow-up data collection was guided by theories emerging from the initial and further data analysis. Categories and the properties of the categories were derived from comparative analysis (Glaser & Strauss, 1967) across and within cases. Provisional hypotheses were then generated and verified by constantly comparing among categories and their properties. These verified hypotheses were integrated into theoretical abstractions.

Participants

A total of 24 students enrolled in a Concepts in Earth Science course participated in this study. Four of them were graduate students working on their degrees on Science Education. Twenty of them were undergraduate students, 19 of them working on their teaching certificates.

Data Collection

The first author observed and audio taped this class nearly every class day. In one class on meteorology, April 10, 1991, one student, Mary, asked her teacher, Dr. H., to explain why the author of the textbook had said "evaporation is a cooling process," because it was contradictory to her understanding. This then generated a class discussion (see Appendix 1 for the discussion transcript, Appendix 2 for transcript notation) on latent heat of evaporation, molecular movement, heat transformation, and change of state. Seven students verbalized their understanding of the concepts. Dr. H. felt the discussion was not as helpful, so he asked a junior college physics teacher, Nan, to explain latent heat on the next class day, April 15, 1991. In order to understand how class discussion, lecture, textbook reading contributed to students' internalization, we designed the first conceptual profile inventory (see Appendix 3). This inventory was administered right before and after the class on April 15, 1991.

In the meantime, the first author interviewed students about their understanding of the information related to the concepts presented in those two days. The teacher and students who actively participated in the class discussions were also asked to report their interpretation of the discussion and their understanding of the concept by listening to the lecture tapes. Based on these interviews and on consultation with three experts in physics, we developed a second conceptual profile inventory (see Appendix 4). This inventory was administered on April 29, 1991.

On the same day the second inventory was administered, one student, Jeneen, asked "why do you feel cooler when the wind blows over your skin," which is one of the examples included in the textbook (Appendix 5, line 6-7) and one of the sample questions that the teacher gave for students to review for their tests. The first author conducted stimulated recall interviews with both Jeneen, the teacher, and another student participated the discussion, Jim, afterwards.

Based on preliminary analyses of students' answers in the second inventory and uanscripts of follow-up interviews, the first author interviewed key informants about their justification for their answers and then asked them questions to help them integrate their knowledge to drive a scientific explanation for the essay question in the second inventory.

Thus, data used for describing this case included a pretest (administered by the teacher on the first day of the symester), relevant information in the textbook used in the course, two conceptual profile inventories, and transcripts of lecture, interviews, and stimulated recall interviews (see Table 1).

Data Analysis

The data analysis primarily followed Vygotsky's microgenetic and semiotic analysis and the method of constant comparison (Glaser & Strauss, 1967). The essence of a microgenetic analysis is to capture the turning points in the internalization process where radical conceptual changes emerge as a result of interaction between intra- and

Table 1

Data Sources

Date	Data source
1/14/91	Pretest
4/10/91	pre-lecture interview transcript: Dr. H's teaching plan
4/10/91	lecture transcript
4/10/91	stimulated recall interview transcript: Caroline
4/10/91	stimulated recall interview transcript: Nanny
4/10/91	telephone interview transcript: Mary
4/10/91	telephone interview transcript: Joan
4/11/91	stimulated recall interview transcript: Dr. H.
4/11/91	stimulated recall interview transcript: Jim
4/14/91	telephone interview transcript: Cathy, Anita, Danis
4/15/91	pre-lecture interview transcript: Dr. H's teaching plan
4/15/91	follow-up lecture transcripts
4/15/91	first conceptual profile
4/17/91	stimulated recall interview transcript: Mary
4/24/91	stimulated recall interview transcript: Dorothy
4/29/91	follow-up interview transcript: Mary
4/29/91	second conceptual profile
4/29/91	out-of-class review section transcripts
5/1/91	stimulated recall interview transcript: Dr. H. & Jeneen
5/1/91	final exam
5/13/91	telephone interview transcripts: Roger, July, Cathy & Joan
	textbook: Essentials of Earth Science
	field notes

interpsychological functions. Semiotic analysis involves analyzing how language mediates inter- and intrapsychological functions. For example, students may change their conceptions after they use language to put together what they comprehend from their own, their teacher's, and their classmates' utterances in the discussion. Microgenetic analysis traces what particular utterance from the discussions contributed to the students' conceptual change; how they interpreted one another; and how they connected the interpretation to their original understanding of the conceptions and changed their preconception. The goal is not only to describe the internalization process but also to explain the origins of these processes and the causal dynamic relations involved in the whole process of internalization.

Thus, the focus of the analysis was on the process of how a student used language to transform knowledge manifested in the interactions with his or her teacher, classmates and/or textbook authors (interpsychological phase) to his or her own conceptualization (intrapsychological phase) of the target concept, the effect of evaporation and condensation on the surrounding air, before, during, and after classroom discussion.

Four basic analysis procedures were involved in this study. First, lectures on April 10th and 15th and both the teacher's and the student's stimulated recall interviews and after-class interviews were transcribed. The lines of each transcript were numbered for easy reference in the analysis process. Second, a preliminary analyses of both the teacher's and the students' parts were noted in the margins of each transcript.

Third, for the purpose of describing the students' internalization process, namely, initial understanding, critical turning points of modification in their conceptualization, and their final conceptualization, transcriptions of the teacher-student interaction and stimulated recall interviews of both the teacher and the students were combined. This provided a picture of both the student's and teacher's intra- and interpsychological processes and the interaction of the two, following the scheme shown in Figure 1.

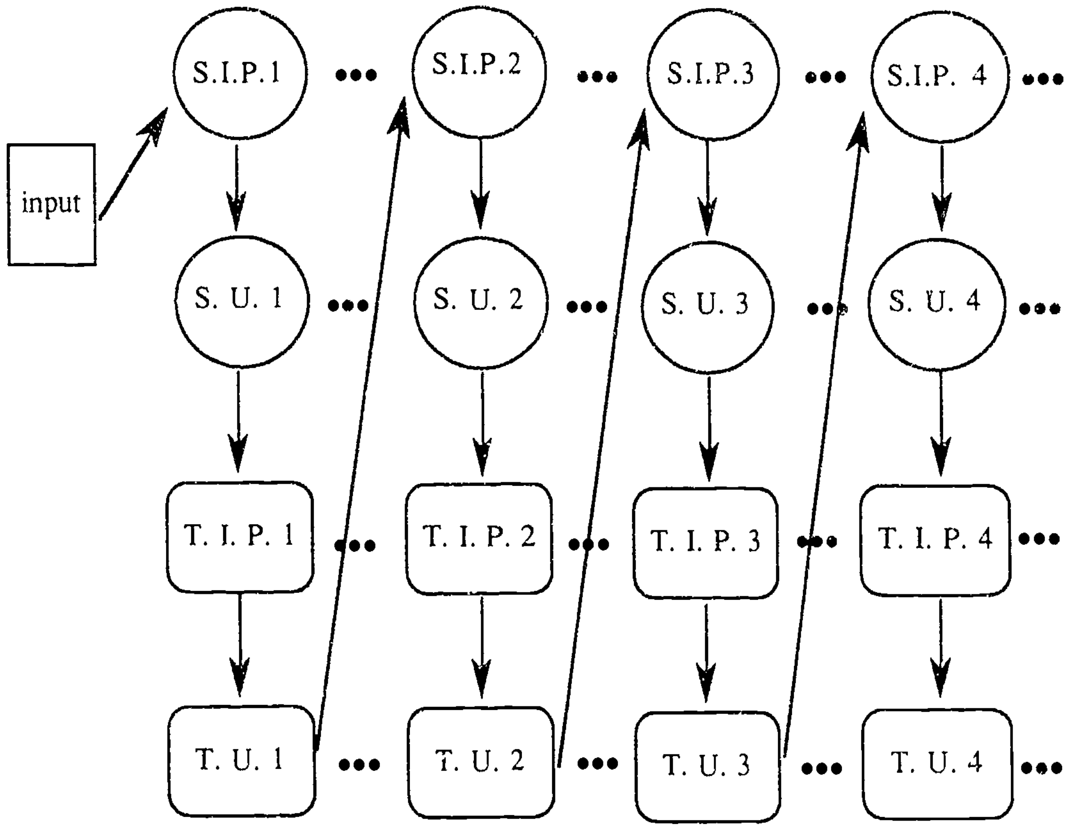
Fourth, in deriving provisional hypotheses for explaining students' internalization process, transcripts of both students' and teacher's stimulated recall interviews and students' follow-up interviews were first categorized separately. Provisional categories and their properties were then derived by constantly comparing evidence within and across cases. Provisional hypotheses were eventually generated and verified by comparison among categories and their properties.

Thus, data analysis was conducted on a case basis with validation of hypotheses being carried across and within cases. The case description of students' internalization processes in this paper included students' initial understanding of concepts from assigned readings and/or their prior knowledge, their comprehension of the lectures and classroom discussions, their difficulties in comprehension, their strategies for monitoring their comprehension during interactions with their teacher, and the critical points when students modified their understanding of concepts.

Descriptions of cases and classroom discussion were validated by participant teacher and students. Based on this feedback from the participants and data from varied sources, i.e. transcripts of classroom discussion, stimulated recall interviews, and follow-up interviews, conceptual profile inventories, and final exam, the descriptions were then modified accordingly .

Results

Based on the analyses of class discussions, stimulated recall interviews, follow-up interviews, and 2 conceptual profile inventories, students were not clear about heat transformation, molecular movement, and energy involved in evaporation and



S.I.P. = Student's intrapsychological processing
S. U. = Student's utterance
T. I.P. = Teacher's intrapsychological processing
T. U. = Teacher's utterance

Figure 1. Intrapsychological and interpsychological processing

condensation. First, we will describe four students' conceptualization associated with their prior knowledge, their textbook reading, and class discussion. Second, we will describe how class discussion, lecture, textbook reading contributed to students' internalization. Third, we will describe how students' difficulties in conceptualization and then pinpoint the importance of the connection between molecular movement, kinetic energy and change of state in understanding of the effect of evaporation and condensation on the surrounding air. Fourth, we will then present some hypotheses that represent reasons for hindering students from conceptualizing evaporation and condensation, and their effect on the surrounding air.

Description of Four Students' Conceptualization

The following description of how four students conceptualized the target concept is based on Vygotsky's microgenesis analysis. We will describe Mary's original spontaneous conception, her insights of the concept on April 10 and April 15, and her conceptual development on April 17 and April 29. A conceptual framework, the relation between molecular movement, energy transformation, and change of states (Figure 2), was used to show what aspects of the concept Mary was leaving out. The conceptualization process of three other students, Joan, Jeneen, and Nanny will also be described by their chronological conceptual progression and analyzed in the same way.

Mary. Having two kids that were at the college level and working during day time, Mary worked on a teacher certificate at an elementary level. She wanted to specializes in earth science. She has taken eleven hours of science courses. Of these eleven hours, only three hours are earth science related. She was not as knowledgeable as some of her classmates that have had twelve hours of earth science related courses. Nevertheless, Mary was very enthusiastic to learn. She actively participated in lab activities and asked many

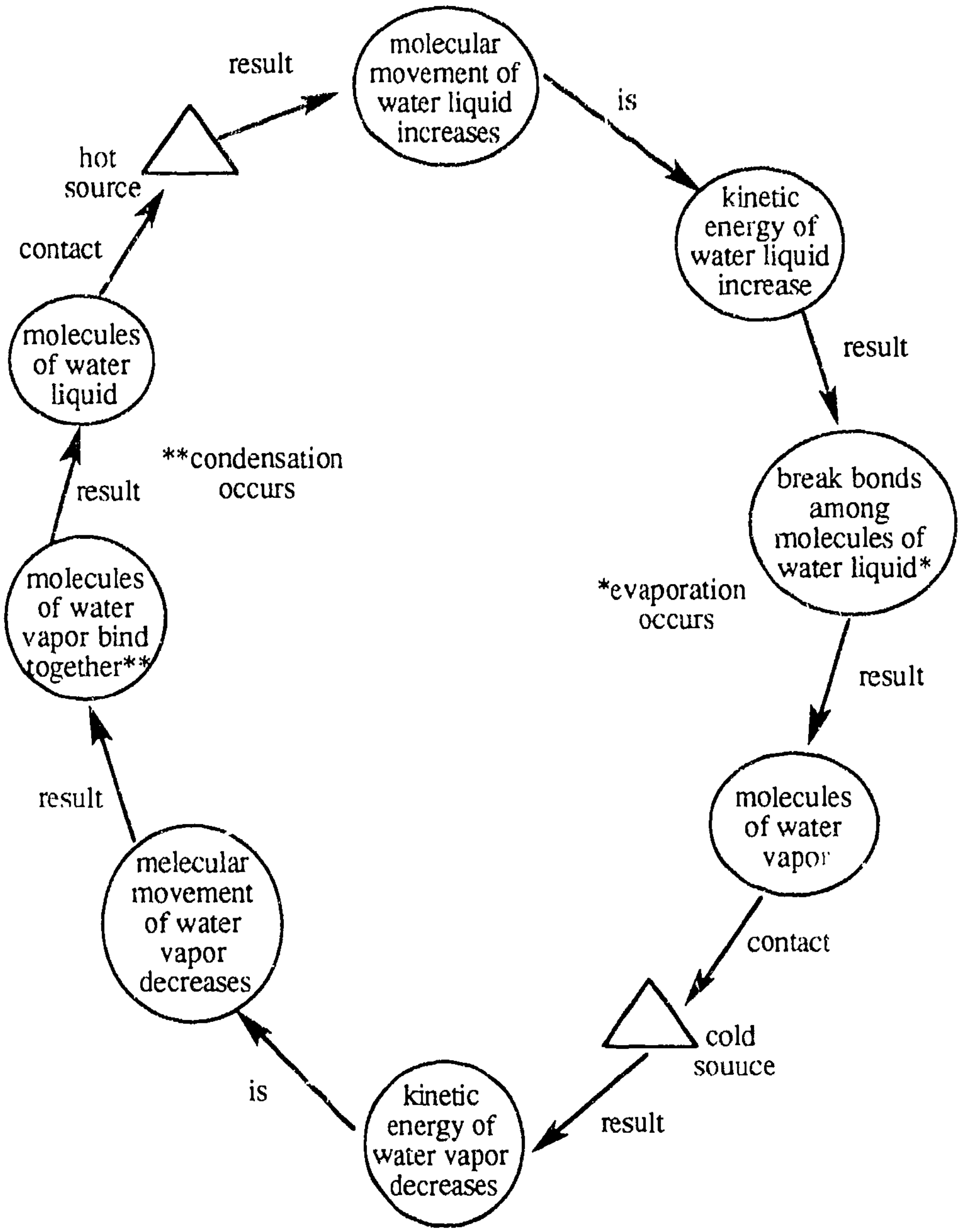


Figure 2. Relationships among molecular movement, kinetic energy, and change of state

questions to monitor her comprehension of the concepts related to the activities. She also asked questions when the teacher presented slides and lectured.

Before Mary came to class on April 10, she had understood that heat is required to change liquid water to water vapor (Appendix 1, line 15-16). She had always thought that evaporation is hot and condensation is cold. She associated evaporation with a hot steamy day and condensation with a cold shower (4/10/91/ESInt: Mary/31-40). Figure 3 is a semantic net showing her spontaneous thought. She found that "evaporation is a cooling process" and "condensation warms the surrounding air," as described in the textbook, were opposite to what she had thought. She was slightly irritated with herself because she thought she had understood the concept from her oceanography course taken the previous year.

The explanation[1] for the effect of evaporation and condensation on the surrounding air that the textbook author, Levin, provided is shown in Appendix 5. His explanation can be summarized by a semantic net shown in Figure 4. In order to evaporate, water molecules need to break away from their neighbor (line 1-3). To break bonds among water molecules requires heat energy (Appendix 5, line 3-5). The heat energy is taken from adjacent environment which cools off the surrounding air. Evaporation, therefore, is a cooling process (Appendix 5, line 5-6). The heat energy used to transform liquid water to water vapor is called latent heat of vaporization (Appendix 5, line 15-16). It resides within vapor during evaporation (Appendix 5, line 16-18). When the latent heat is released to the environment during condensation, this warms the surrounding air (Appendix 5, line 18-20).

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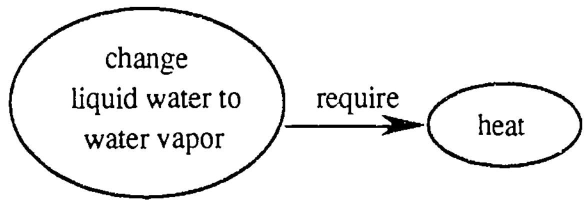
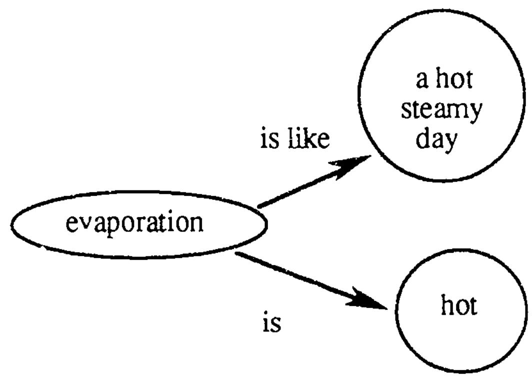
[1]The explanation provided by Levin is sufficient for students who know molecular movement and kinetic energy and their relationship of change of states. An explanation without presuming students' knowledge is in Appendix 7.

Mary's description of her question in the lecture of April 10, 1991

27 Mary: "I understand
28 when it goes from liquid
29 to vapor requires heat to
30 do that" (4/10/91/ES
Lecture/line 27-30).



Mary's report of her understanding of evaporation and condensation on April 10, 1991



Mary: "... when I think of evaporation, I'm thinking of a hot steam-day where water is vaporated. And I'm hot, you know. So, that's why I couldn't see it, visualize it as a cooling process. The same way is with condensation. When it condenses ... when you have precipitation, they said that you have a gain of heat in the atmosphere. To me, I don't understand cause when you have a cool shower, it cools things off" (4/10/ESInt: Mary/ 31-40).

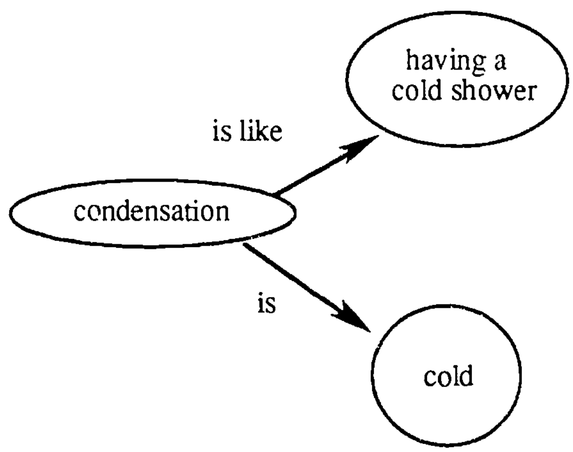


Figure 3. Mary's spontaneous thought of the effect of evaporation and condensation on the surrounding air before the discussion on April 10, 1991

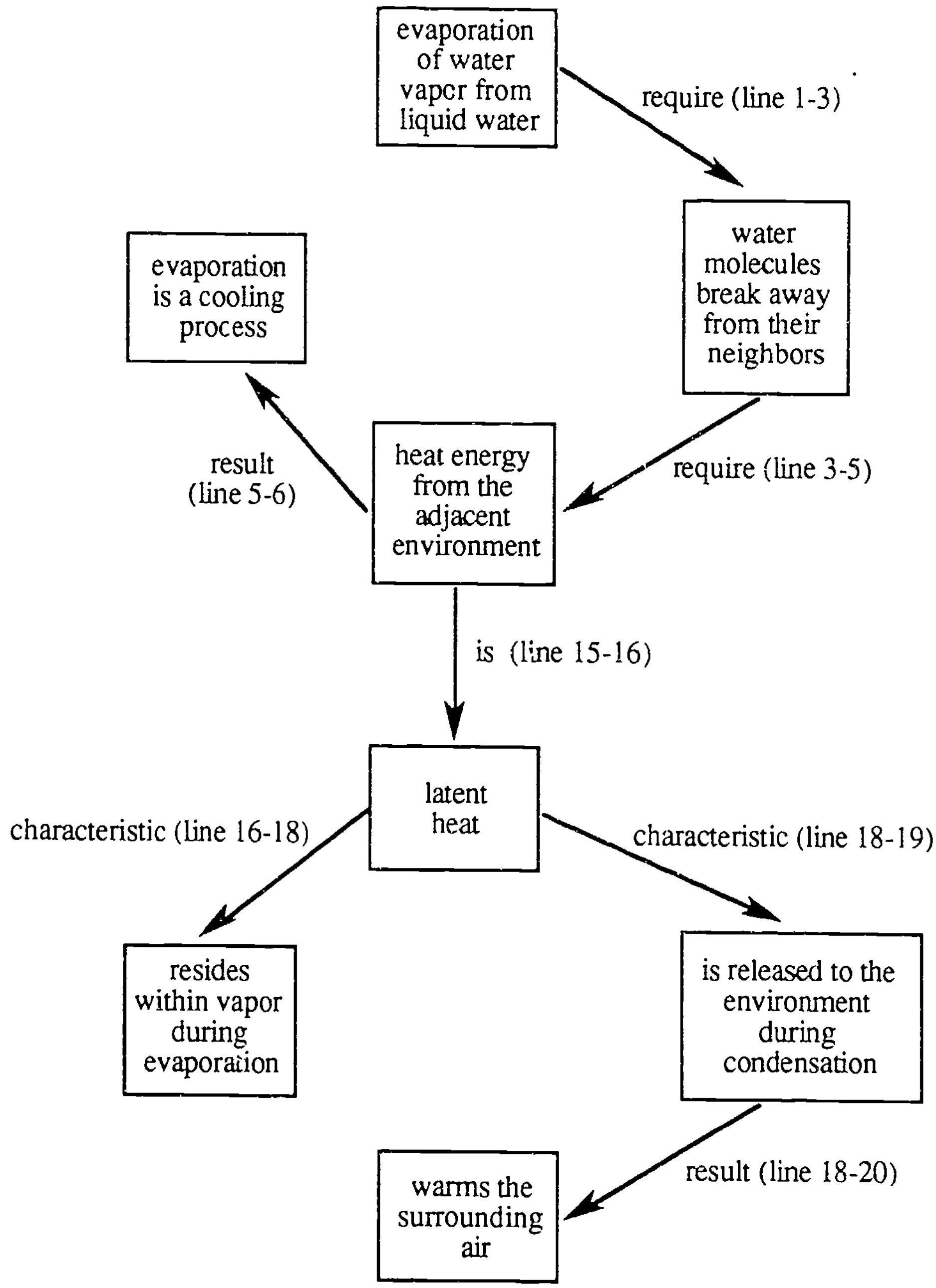


Figure 4. Information about "evaporation is a cooling process" and "condensation warms up the surrounding air" from textbook (see Appendix 10 for reference)

On April 10th, Mary realized that she had been thinking of evaporation in terms of temperature (Appendix 1, line 148-149) when she was listening to one student, Jim, use "energy" to explain evaporation (Appendix 1, line 139-142 & 147). This first turning point, resulting from her interaction with Jim and Dr. H., is summarized by a graph in the right column of Figure 5. The graph is a short version of the interaction between inter- and intrapsychological process (refer to Figure 1). The transcript of the interaction between Jim, Mary and Dr. H. is included in the left column of Figure 5 for reference.

According to her report after the class, which was included below the graph in Figure 5, Mary felt that if she had thought in terms of "energy," she would not have been confused. However, she used "heat" instead of "energy" in the discussion (Appendix 1, line 148). In addition, Mary still thought of temperature as a measure of heat (4/10/91/ESInter: Mary). Scientifically, temperature is defined as the average amount of kinetic energy; while kinetic energy is the movement of the molecules.

After the 10-minute discussion on molecular movement, kinetic energy, and change of matter on April 10th, Mary still was not sure where energy transformed to and how it related to change of matter. She reported that Jim's explanation was clearest, but she felt that she didn't have it clear in her mind yet because she had received "bits and piece of information from several people at one time" and had not had time to "think it all the way through."

In sum, Mary did not think of change of states in terms of energy and molecular movement. This was because she did not know or she knew but did not incorporate the following information into her understanding of change of states: (1) molecules in each state of water move constantly; (2) molecular movement is kinetic energy; (3) temperature

Jim: "We have a liquid, we're going to a gas ... I have to put energy into it. I can put energy into it more and more. I'll get to a point at which it has as much energy as possible as a liquid. In order to keep that energy." =

Dr. H: = "Now, wait, how do you get to the point where it // has as much"

J: "I'm trying to] avoid getting into"

H: // "I know."

J: "heat] versus temperature and things like that." =

Mary: = "See, I think that's what I'm confused. I think of heat as temperature."

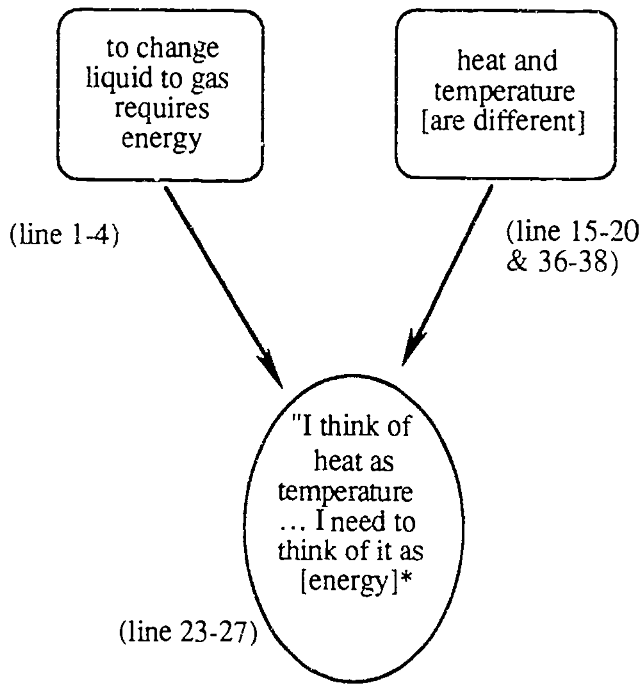
J: "OK."

M: "And, I need to think of it as"

H: // "Temperature as a measurement of"

M: "a measure of"] =

J: = "The average amount of kinetic energy ... Kinetic energy would be the movement of the molecules ... you have to distinguish between heat and temperature"



*In her retrospective report, Mary said. "If I didn't think of it as temperature, I think I'll be alright ... If I just view it simply as energy, then I don't think I'll be confused. It's because I'm adding the term 'temperature' to it, which is a measure of heat. That's where I get confused" (4/10/91/ESInt: Mary/135-139).

Figure 5. Mary's first turning point where she realized that she should think of evaporation in terms of energy rather than temperature on April 10, 1991

is the average amount of kinetic energy; (4) heat is the total amount of kinetic energy; and (5) change of kinetic energy (or movement of water molecules) results in change of state.

The fact that Mary did not know about the relationship between molecular movement, energy, and change of state is confirmed by the fact that she did not know that change of state is mainly dependent on latent heat rather than just changes in temperature on April 15, 1991. Her second turning point resulted from Nan's explanation is illustrated by a semantic net, enclosed in circles, below her verbal report in the right column of Figure 6. The transcript of the interaction between Mary, Nan, and three other students is included in the left column of Figure 6. The semantic net, enclosed in squares, below the transcript of the discussion shows Nan's explanation of how change of state requires latent heat rather than temperature.

Mary thought that change of temperature resulted in evaporation because all she knew was that heat was required for evaporation. She did not know that change of state is mainly determined by energy. Nan did not explain latent heat in terms of molecular movement and energy. Jim and Roger had mentioned molecular movement and energy on April 10th, but Mary did not pick up the information or incorporate it into her understanding of change of state at the time. Her second turning point was a result of her applying "energy," which she realized at her first turning point, to change of state.

According to Mary's reports (see transcript on the left column of Figure 7) on April 17, she interpreted Jim's explanation (see Figure 8) as that gas was taking energy with it during evaporation (Figure 7, line m-o) because gas can accommodate more heat than water (Figure 7, line g-i). Therefore, evaporation cooled off the land mass (Figure 7, line u-v). Here, Mary understood Jim's explanation of evaporation in terms of energy (Figure 7, line

Lecture transcripts of April 15, 1991

Nan: "... if we look at the change from liquid to gaseous state, we don't have changes in temperature ... a certain amount of heat that is required to do that without a chang- ing in temperature to change the state of matters is the latent heat, in this case, of vaporization ... Any questions? Yes."

Mary: "If you have chaning heat, does it not always register in the temperature (or it's not been report.)"

Kay: "That's what she's saying (that it doesn't.)"

Student 1: "So, is it minute or what?"

Nan: "No. It's absorbed complet-, it's absorbed in the process of changing state or given off in going from liquid to solid state. OK. So, it does not register as the changing temperature as much as you notice that there's a certain amount of substance changes states."

Mary's new insight resulted from listening to Nan's explanation that she reported on the first conceptual profile inventory on April 15, 1991:

"I didn't realize that the temperature does not vary during the process of change of state."

Mary's retrospective report on April 17, 1991

Mary interpreted Nan's explanation (line 1-8) as:

(1) Mary: "You didn't have to have
(2) a change in temperature in order
(3) to have change of state. It was
(4) that latent heat (respect.) So, ( )
(5) energy that was converting the
(6) property from one state to
(7) another and not a change in
(8) temperature."

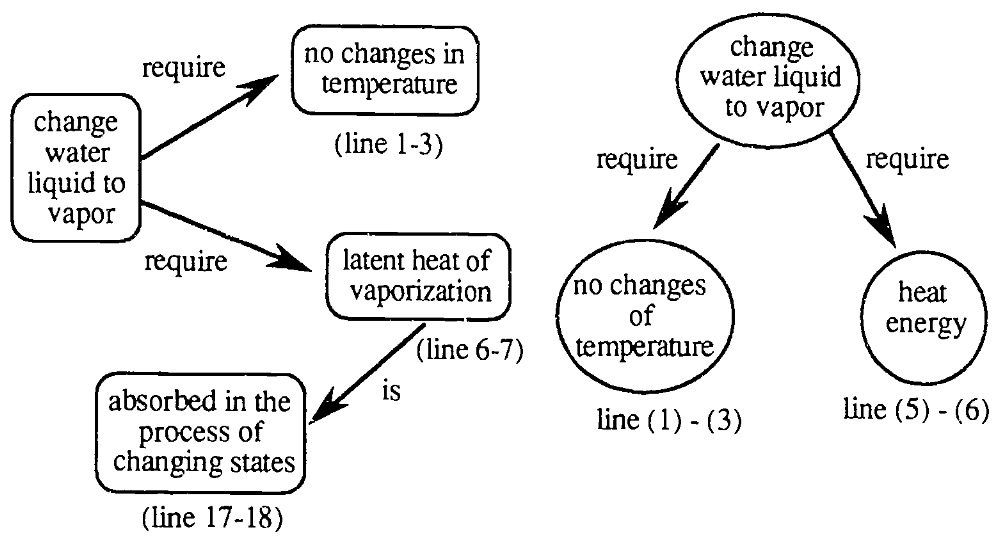


Figure 6. Mary's second turning point: she realized that change of state depends on energy rather than temperature on April 15, 1991

Mary's retrospective reports on April 17, 1991

[Mary interpreted Jim's explanation in class on April 10, see Appendix 11, line 168-171 as:]

a Mary: "The water will withhold
b so much heat before it converts
c to vapor."

[Mary interpreted Jim's explanation in class on April 10, see Appendix 11, line 171-174 as:]

d Mary: "I felt little foggy here.
e I guess this is a form until ( )
f (water) to gas, the molecules
g (burn) their parts. And they
h can accommodate that excess
i heat, spread it out, whereas in
j this form, you can only fit so
k much in a box. You cannot fix
l any more until it just spills over
m ... it's like he's saying the gas is
n taking the heat with it in the form
o of energy. And, see, I think it
p takes the temperature with it."

Mary's explanation of why evaporation is a cooling process on April 17, 1991

q Mary: "... latent heat is used in
r the process of changing from
s liquid to gas. And that gas is
t carrying that heat away with it so
u that it does cool off the land mass"
v (4/17/91/ESSRI: Mary/466-468).

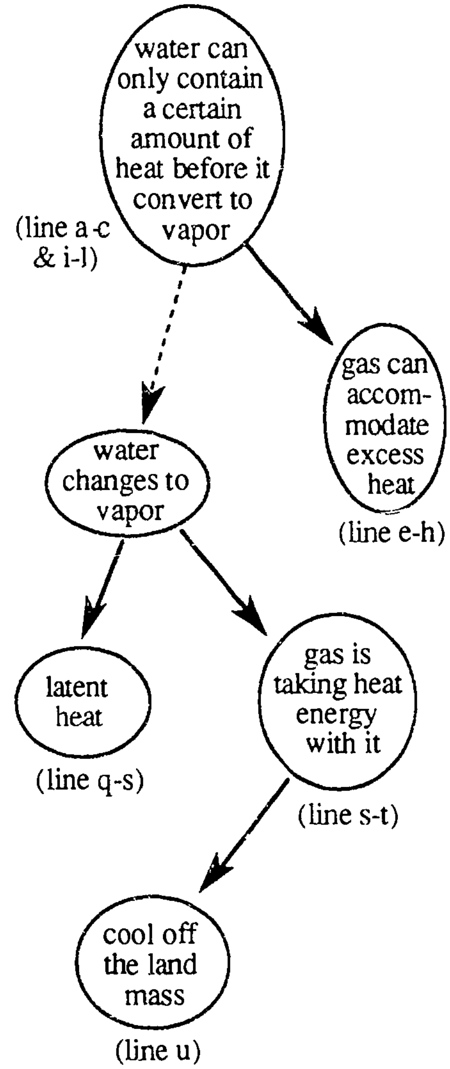


Figure 7. Mary's understanding of "why evaporation is a cooling process" on April 17, 1991

Jim: "Once I have a certain mount of heat in that, at a certain point that can no longer contain that heat, if you will, in that state. In order to maintain that amount of energy, it has to go to a gas, as gas has that energy not, that was the latent heat of vaporization. OK. So, if you can picture these molecules moving around, then it got all loose changes with its energy if you will." (4/10/91/ES lecture transcript, see Appendix 11, line 168-174)

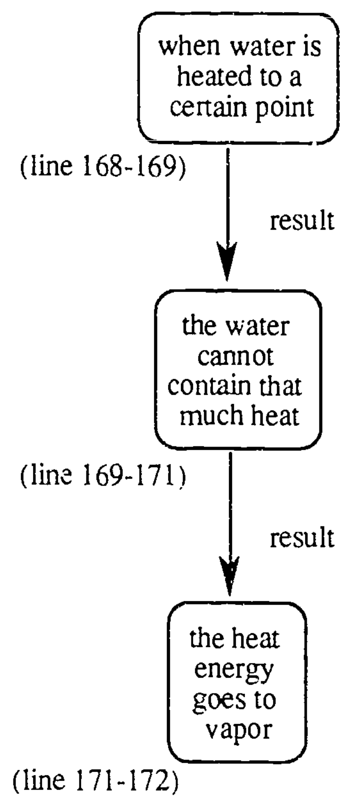


Figure 8. Jim's explanation of energy transformation and evaporation on April 10, 1991

m-o), but because she did not know how to relate energy to molecular movement, she felt "foggy" about gas accommodating excess heat (Figure 7, line d-i).

Regarding the relation between kinetic energy and molecular movement, Jim mentioned three aspects in his explanation: (1) kinetic energy is the movement of the molecules; (2) the increase of energy results in the increase of molecular movement; and (3) temperature is the average amount of molecular movement (Appendix 1, line 156, 157-158, & 154).

From Jim's explanation, Mary should have been able to infer that more energy resides in water vapor than in liquid water because she knew that water needs to absorb energy to vaporize. However, she did not relate molecular movement to energy. This is why when she heard Jim say "[the energy] goes to a gas" (Appendix 1, line 170-171), she interpreted his comment to mean that gas is taking heat energy with it (Figure 7, line m-o) rather than kinetic energy resides in the molecules of water vapor. This interpretation led Mary to draw the conclusion that evaporation cooled off the land mass because gas was carrying heat away with it. Mary's conclusion was based on the effect of vaporization after evaporation had occurred rather than during the process of evaporation. In fact, it is during the process of evaporation that the energy in the surrounding environment is transformed to evaporate the liquid water which is how it cools the surrounding air.

On April 29, 1991, Mary started to incorporate molecular movement and energy into her explanation of evaporation and its effect on the surrounding air.[2] The two

[2]Mary asked me to let her know how Jim explained evaporation is a cooling process because she heard Dr. H. mention that Jim had a good explanation when they had a conversation out of the class. I interviewed Jim and asked him to explain it to me on April 18, 1991. On April 29, 1991, I played Jim's explanation to Mary, and asked how she related it to her question, why evaporation is a cooling process. Appendix 11 is a transcript of the interview that I had with Mary on that day.

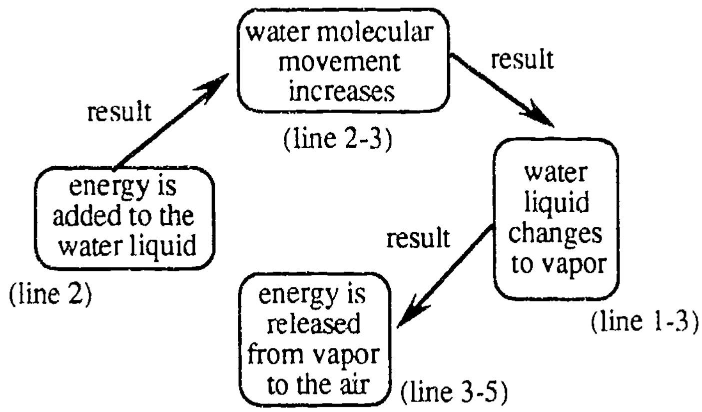
semantic nets in Figure 9 depict Jim's explanation and Mary's understanding of why evaporation is a cooling process, respectively.

In Figure 9, Mary was probed to about evaporation in terms of energy (Appendix 6, line 48-56) and molecular movement (Appendix 6, line 57-63) but she still did not conceive of molecular movement as energy. Mary realized that the area containing water could be cooler (Appendix 6, line 70-71) because heat energy was absorbed by liquid water. However, Mary was still thinking that the energy went with vapor when evaporation occurred. She then inferred that the air surrounding vapor would not be cooler (Appendix 6, line 71-72) because the heat energy would then be absorbed by the surrounding air that the vapor went into (Appendix 6, line 72). Again, Mary was still thinking of the effect of evaporation after evaporation occurred rather than during the process of evaporation. However, this time she was thinking of the surrounding air into which the vapor went rather than from which the vapor came as she had been thinking on April 17th.

Because Mary did not perceive molecular movement as energy and relate it to the change of states, she thought that energy went with the vapor because the vapor had absorbed energy. Therefore, she still could not explain why condensation warms up the surrounding air on April 29, 1991.

In sum, the conceptualization process that Mary went through can be summarized as that she (1) related the change of states to temperature (Figure 3); (2) realized that she should think of change of states in terms of energy (Figure 5); (3) realized that change of states depends on latent heat rather than on the change in temperature (Figure 6); (4) inferred that after evaporation, energy goes with the vapor, which results in cooling the

Jim's explanation of "why evaporation is a cooling process



Mary's conceptualization on April 29, 1991

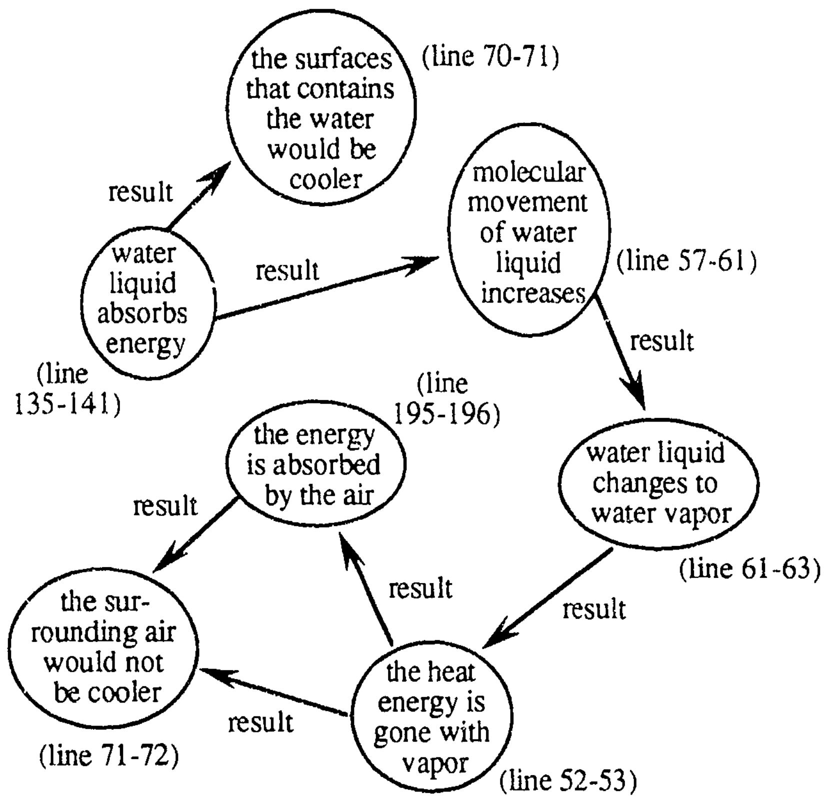


Figure 9. Mary's conceptualization of "why evaporation is a cooling process" on April 29, 1991

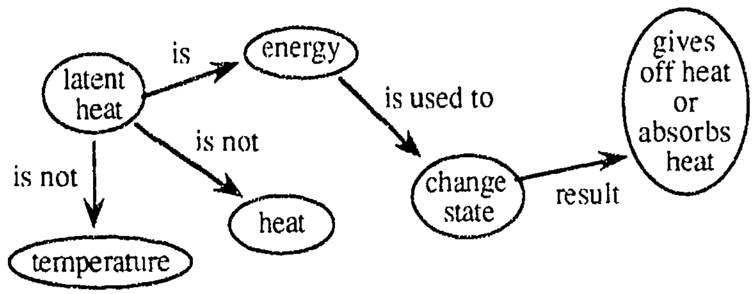
surrounding air (Figure 7); (5) realized that evaporation cools off the surrounding air when liquid water absorbs energy from adjacent air (Figure 9).

Joan. Joan had forgotten the information about evaporation and condensation that she had learned in her senior year in high school. She did not read Chapter 14 before she came to class on April 10, 1991. She was reading the part pertaining to latent heat when Mary asked the question in class. On April 10, 1991, when Dr. H. asked her to explain latent heat, Joan could not remember the chart that had helped her understand latent heat in high school. When the first author interviewed her after that day, she remembered specific heat, a specific scientific term, but she could not retrieve her knowledge of it and contrast it to latent heat.

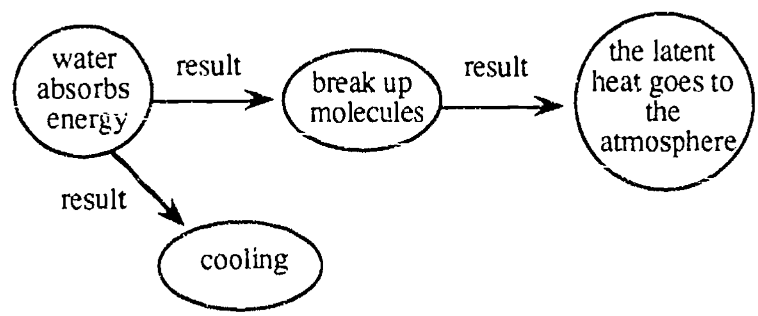
Using semantic nets, her understanding of the concept on the April 10th is depicted from three angles. First, Joan related latent heat to energy rather than to heat or temperature (see the first semantic net in Figure 10). Second, she related change of states to energy, the bonds among molecules, and the effect on the atmosphere. In evaporation, the increase of energy resulted in the breaking of the bonds among water molecules and the decrease of the temperature in the atmosphere (see the second semantic net in Figure 10). By contrast, in condensation, the release of energy resulted in closely tying the bonds among the molecules of water vapor and an increase in the temperature of the atmosphere (see the third semantic net in Figure 10).

Third, she did not know why energy was released in condensation. She said, "... energy is sort of no longer needed by the vapor in the molecules." This reflects that she thought of change of states in term of breaking of the bonds among molecules other than molecular movement. It also showed that she did not perceive energy in terms of molecular

Joan's understanding of latent heat on April 10, 1991



Joan's understanding of evaporation



Joan's understanding of condensation

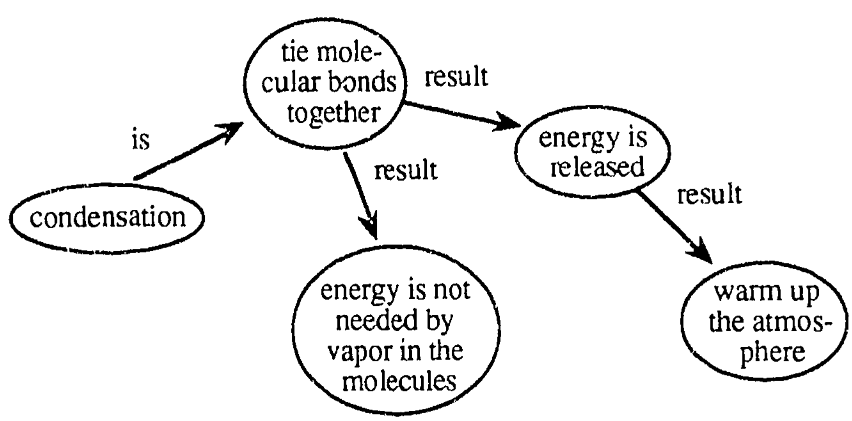


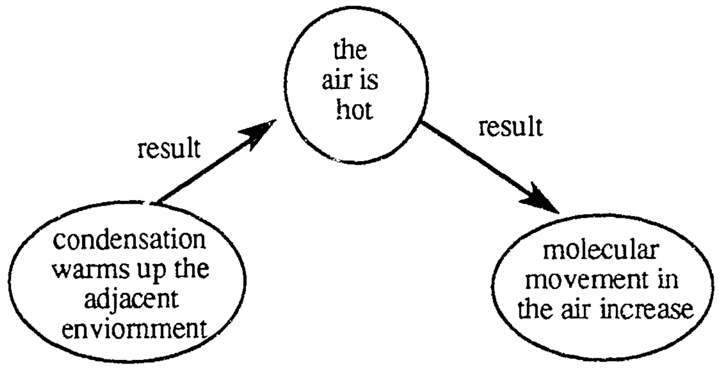
Figure 10. Joan's understanding of "latent heat," "evaporation," and "condensation" on April 10, 1991

movement, as revealed in her written reports on April 29, 1991, her final exam on May 1st, and in the follow-up interview[3] on May 15, 1991.

There are two aspects in Joan's written reports that were crucial for her conceptualization on April 29th. First, Joan did not even consider that molecular movement had anything to do with change of states. She reported, "I just think of bits of sweat, I don't think about molecules in it moving." The question pertaining to molecular movement in the second conceptual profile inventory asked Joan to think of change of states in terms of molecular movement. She mixed up the molecular movement in evaporation and condensation. Based on (1) what she had learned from the discussion on April 10th that condensation warmed up and evaporation cooled down the adjacent environment and (2) the speed of molecules increased when the air was hotter, Joan associated the molecules in the air speeding up with condensation and the molecules in the air slowing down with evaporation (see Figure 11).

Second, in terms of where the heat came from, Joan thought that molecules of perspiration absorbed heat from air around the skin. She thought that because the energy in the air was used to evaporate perspiration, the air was cooler. Actually, the molecules of perspiration absorb heat from our body, which is why we feel cooler. In her final exam on May 1st, 1991, Joan made the same mistake in one of the questions, which was "Why do you feel cooler when the wind blows over your skin?" She was surprised that she was wrong and did not understand why her teacher underlined "wind will feel cooler." She reported,

[3]On May 15, 1991, I asked Joan to explain her reasons for rating her confidence level differently for each true-false item. Her reports helped me interpret her answers to the second conceptual profile on April 29, 1991.



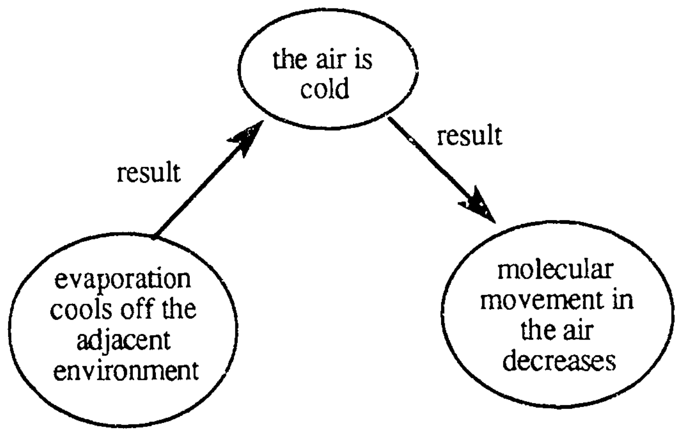


Figure 11. Joan's conceptualization of molecular movement and change of states on April 29, 1991

I was like, god, we went over it so many times. I still got that wrong. That was how I felt. And I was kind of surprised and I thought, god, I thought I knew it! It was never made clear where the heat was taken from, you know. I don't remember him ever saying it was taken from your skin, you know. If I had, I certainly would put it down. But I never heard him say it was taken from the wind either. So, I just made a guess.

Although she became clearer about where the energy really came from as we talked more on May 15th, 1991, Joan still kept retreating to her original thought and said, "I still think they took the energy from the wind," as if she was not totally convinced. In our conversation about what wind had to do with cooling body temperature, Joan resolved her question by bringing in an alternative to incorporate into her previous beliefs. She said, "... it's not exactly in the wind and not exactly from the body because it's in between" because she thought that friction, resulting from wind blowing over skin, was the energy source for evaporating perspiration.

Secondly, she still could not explain why energy was released in condensation even though she realized that the increase of the energy resulted in the increase of the molecular movement and started to relate the molecular movement to condensation. She still said, "... the molecular will slow down and when they bond together, I guess they have like extra heat and they don't need it. And so, they're just sort of getting rid of it when they bond together." Compared to her explanation on April 10th, Joan was now adding molecular movement to her explanation, but she still did not perceive molecular movement as energy and incorporate it into her explanation.

Jeneen. Jeneen was working on her elementary school teacher certificate. She planned to graduate next year and teach at a kindergarten and then continue her education.

Jeneen hoped to learn basic concepts of earth science from this course. She had already taken fifteen credit hours of science courses and six of them related to geology, but she had never had meteorology before. Jeneen did a very good job in all the written examinations in the course. Dr. H. considered her a bright student.

Although she reported that "[asking] questions help [her] understand better," Jeneen never asked questions in the class. Even in the laboratory activity, where many students who did not speak up in the lecture asked more questions, Jeneen seldom asked questions. She said that she did not want to ask a dumb question in front of the class with all attention focusing on her. However, in an informal review session after the last class day of the semester, April 29, 1991, Jeneen asked many questions even though there were five other students with her because she had to resolve her questions before the final.

Jeneen was one of the two thirds of the students who did not voice their understanding of the concept on April 10th. From the pretest she took on January 14, 1991 and her written reports in the second conceptual profile inventory on April 29, Jeneen mixed up the heat transformation involved in evaporation and condensation. She thought that heat was given off during evaporation. Second, she did not understand where the heat came from, how the heat was given off, and what the heat was used for. Third, she did not think of change of states in terms of molecular movement. When she was asked to think of change of state in terms of molecular movement in the second conceptual profile inventory, Jeneen was not sure of the relation between molecular movement and change of states, which Jim had mentioned briefly in the discussion on April 10th (Appendix 1, line156-158 & 167-174).

Fourth, Jeneen knew that evaporation is a cooling process at a knowledge level from reading the textbook but did not understand it. She reported, "I cannot just read it and understand it. I have to have someone talk to me ... I have to picture it in my mind or have a real life example." Jeneen's answer on the second conceptual profile inventory, which was given at the beginning of class on April 29th, was a result of her lack of knowledge of the relationship between molecular movement and energy and her misunderstanding of the heat transformation involved in evaporation. The first semantic net in Figure 12 depicts her explanation of why you feel cool when wind blows on you[4].

After the class on April 29, Jeneen, Jim, Roger, Caroline, Mary, and Judy stayed in the classroom and asked Dr. H. questions that were included in the list of sample questions for the final examination. At the end of this informal review session, Jeneen asked, "I know this is just an easy question, but I don't understand. For instance, why do you feel cool when the wind blows on your skin?" From the answers provided by Dr. H. and Jim, Jeneen understood that heat comes from the body and goes to vapor (4/29/90/ESAfter Class/209). The second semantic net in Figure 12 represents her conceptualization of the concept after she had interacted with Dr. H. and Jim on April 29th.

Consistent with her preconception that heat was released during evaporation, Jeneen still thought that heat was released from the body (5/1/91/ESSRI: Jeneen/71 & 101-2) rather than that perspiration absorbed heat from the body. She concluded that the body felt cooler because when the wind hit the skin the heat was given off from the body and went into vapor. She still did not connect the heat from the body to the evaporation of perspiration. Compared to Joan, Jeneen had much more basic knowledge of molecular movement, energy, and change of states, and needed only to integrate them to explain why evaporation is a cooling process.

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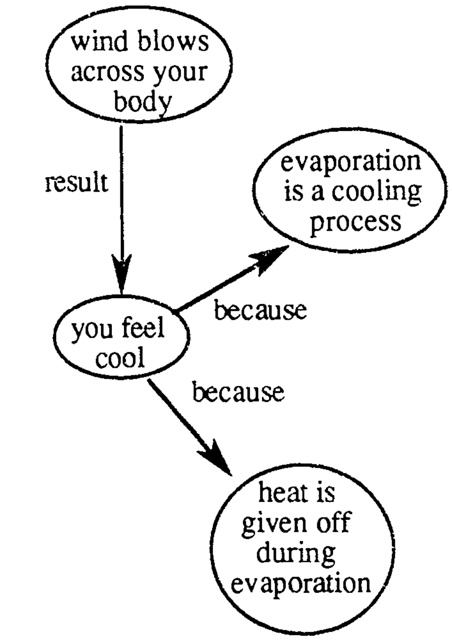
[4]Jeneen thought the essay question, explain the effect of perspiration on the body using the notion of heat exchange in molecular terms, in the second conceptual profile was the same question, why do you feel cool when the wind blows on you, as her teacher gave in the sample question for Chapter 14, Moisture in the Atmosphere.

Jeneen's explanation of why you feel cooler when the wind blows over your skin on the essay of the second conceptual profile inventory

"When wind blows across your body and you are perspiring, you will feel cool because evaporation is a cooling process. During evaporation, heat is given off ??" [Jeneen marked two question marks in the end of her answer. She told me that it was because "I know evaporation is a cooling process. And the heat is given off. Then, after that I dont' know. I didn't know where the heat went. I didn't know where it's coming from."]



Jeneen's report of her understanding of "why you feel cooler when the wind blows over your skin after interacting with Dr. H. and Jim

Jeneen: "... when the wind hits on your skin, that's when the heat is ... taken away from your body ... I wasn't sure where the heat was coming from. But, if the heat is from within your body that is released, and I think that ... it is the whole cooling process and how it works."

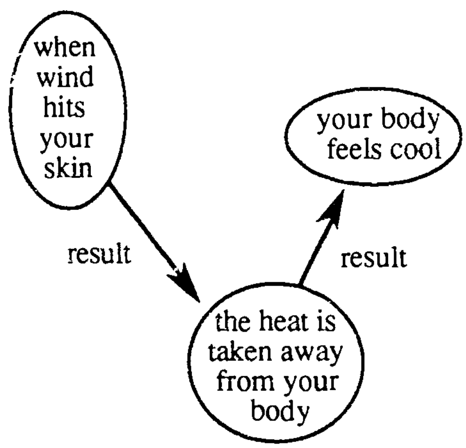


Figure 12. Jeneen's understanding of "why you feel cooler when the wind blows over your skin" before and after her interactions with Dr. H. and Jim on April 29, 1991

Nanny. Before the discussion on April 10, 1991, Nanny had never heard of "latent heat" before. She reported that she had not read Chapter 14 yet, and that she was not good at physics. She had a vague understanding of energy transformation and of how molecular bonds are broken and tied back together in evaporation and condensation. However, she grasped the gist of the concept very accurately after the discussion.

After the discussion on April 10th, the first author asked Nanny to listen to the lecture tape and report what she was thinking at the time and her understanding of the concept[5]. Figure 13 is her interpretation of latent heat. There are two aspects of her conceptualization worth mentioning here. First, Nanny thought of water and vapor in terms of molecules. Second, she related energy to the bonds among molecules, energy, and change of states. The increase of the energye resulted in the breaking of the bonds among water molecules and evaporation while the release of energy resulted in the close tying of the bonds among the molecules of water vapor and condensation. Therefore, Nanny inferred that there was more energy contained in the molecules of water vapor than in water molecules.

Nanny's written reports on April 29, 1991 showed that she did relate molecular movement to evaporation. A semantic net in Figure 14 depicts her explanation of the effect of perspiration on the body, the essay question on the second conceptual profile inventory (Appendix 4). The text above the semantic net is her answer to the essay question. The fact that Nanny knew the relationship between molecular movement and change of states was also confirmed by her answers to the true-false items about molecular movement and

[5] I interviewed Nanny after Caroline. While I was interviewing Caroline. Nanny was reading the information about latent heat in the textbook (see Figure 5). The reports that Nanny gave on April 10 was what she incorporated from the information discussed on April 10th and the explanations in the textbook into her prior knowledge. However, her question (4/10/ESLecture/line 354-364) and comment (4/10/ESLecture/line 419-422) made in the class still represented her thought during the class, providing a source of information for verifying her retrospective report after the class.

LC: "You mentioned that you read information in the book and you had a better understanding now. Would you tell me what is your understanding of latent heat?"

Nanny: "Well, my understanding of it is that when water is in liquid form, it is closely bound to the molecules next to it. And energy must go in to that to break those bonds. When the energy goes into it, it stays on those molecules. In other words, the molecules, when they are separated, contain more energy than they do together. So, when they come together again, that heat comes back out. Latent heat is the heat that will break those bonds initiallly going in are when those bonds (are) again that heat will come out because they are less energy stored in water molecules which combine than water molecules which is separate."

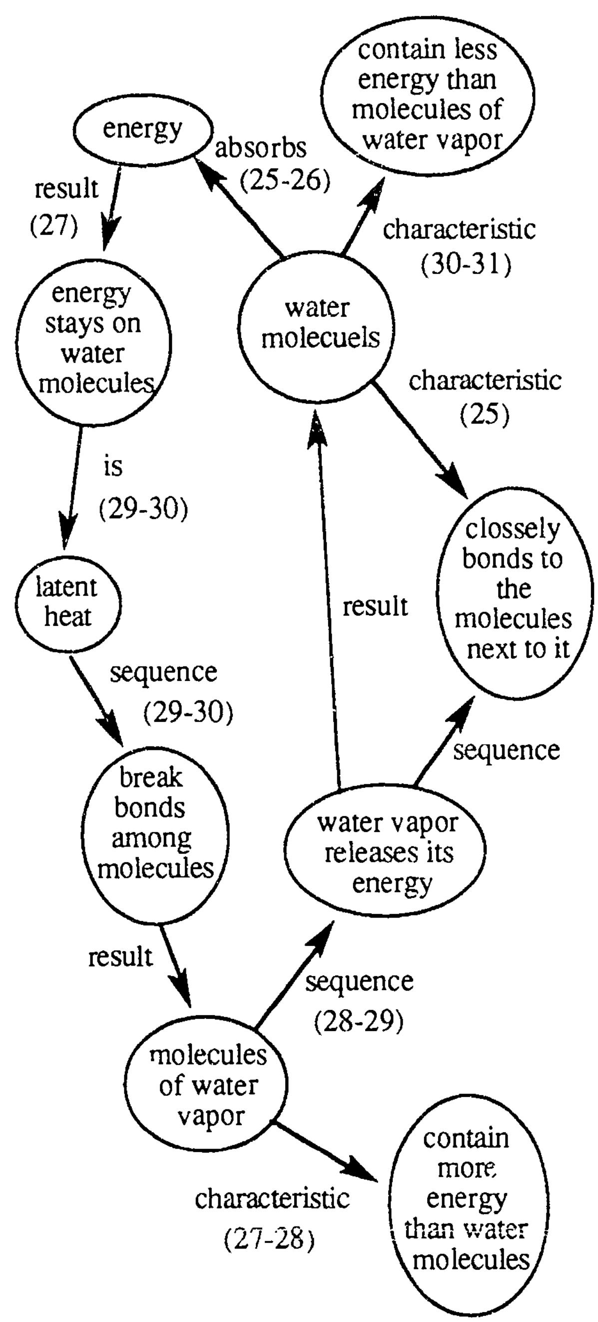


Figure 13. Nanny's interpretation of information about latent heat in the textbook on April 10, 1991

Nanny's written explanation of "the effect of perspiration" on the second conceptual profile inventory

1 "Perspiration (liquid on the body surface) evaporates,
2 taking heat from its surrounding (the latent heat of
3 evaporation.) Part of its 'surrounding' is the body
4 surface and the air adjacent to the body surface.
5 These are cooled as the liquid draws heat from them
6 in order to increase the activity of the water molecules,
7 which is necessary as they go from liquid to gas."

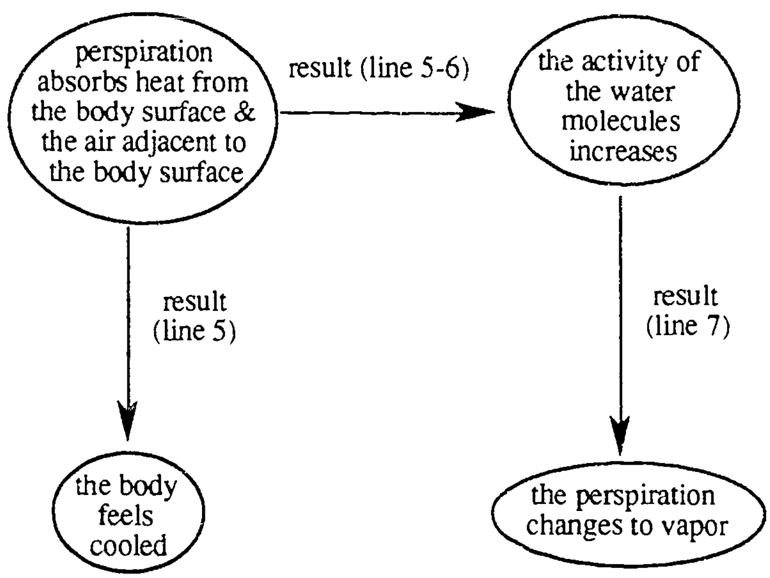


Figure 14. Nanny's explanation of "the effect of perspiration" on April 29, 1991

change of state. In sum, Nanny explained the cooling effect of evaporation from delineating the relationship between molecular movement, energy, and change of state. Compared to Mary, Joan, and Jeneen, Nanny had all the basic subconcepts, which she incorporated from the class discussion and textbook, needed to conceptualize the effect of the change of states on the surrounding air.

How Class Discussion, Lecutre, And Textbooking Reading Influenced Students' Internalization

From the analysis of the two conceptual profile inventories that were administered on April 15 and 29th, not all the students picked up the information discussed on April 10th and/or integrated it to relate it to meteorology or to explain a similar phenomenon, the effect of perspiration on the human body.

In order to understand how class discussions had influenced the students' conceptual learning, we designed the first conceptual profile inventory (see Appendix 3) to ask the students about (1) where they had learned about latent heat; (2) how the concept related to meteorology; (3) and how the class discussions of the first, (4) and second day had contributed to their understanding of it. We asked them to answer the first three questions before the class on the April 15th and to answer the fourth question right after the class. Sixteen students (67%) returned the first conceptual profile.

The results showed that (1) the discussion on April 10th contributed little to these 16 students' knowledge of latent heat; (2) 31% of the 16 students could not articulate how latent heat related to meteorology; and (3) more than half of these 16 students had not comprehended or internalized the concept yet.

According to these sixteen students' reports, the class discussion on April 10th and the textbook did not contribute much to the students' knowledge of the concept. Two of these 16 students indicated that 50 % of their knowledge of latent heat was from the class discussion on April 10th. Three of these 16 students indicated that 50 % of their knowledge of latent heat was from reading the textbook.; while, 8 of these 16 students indicated that 50% of their knowledge of latent heat was acquired from courses they had taken before. Table 2 shows the percentages these students assigned for their knowledge of the concept.

Two students reported that the discussion on April 10th clarified and helped their understanding of the concept. However, six students (about 38%) indicated that their knowledge of the concept did not change as a result of the discussion; while three students (about 17%) reported that the discussion confused them. Mary and Joan were two of these latter three students.

Half of these 16 students considered that change of states or change in temperature was how latent heat was related to meteorology. There were 5 of them who simply defined "latent heat"

as heat needed to convert liquid water to water vapor without relating it to meteorology. One student mentioned humidity as how latent heat related to meteorology; while two students did not answer the question.

The fact that the students did not yet comprehend or internalize latent heat was revealed from their response to Nan's explanation on April 15th. Sixty-nine percent of these 16 students did not know that the change of state depended on latent heat rather than changes in temperature until that day.

Table 2 Students' knowledge[6] source of the concept "latent heat"

1. from class students took previously		
# of students	percentage	subtotal & total percentage
3	100%	
1	85%	
1	75%	
1	70	
1	60%	
1	50%	subtotal= 8 = 53%
1	40%	
2	10%	total= 11 = 73%
2. from reading the textbook for this Earth Science class		
# of students	percentage	subtotal & total percentage
1	80%	
1	75%	
1	50%	subtotal = 3 = 20%
1	40%	
2	30%	
1	15%	
1	14%	
1	10%	total = 9 = 60%
3. from class discussion of April 10th		
# of students	percentage	subtotal & total percentage
1	60%	
1	50%	subtotal= 2 =13%
1	25%	
1	20%	
2	15%	
3	10%	total= 9 = 13%
4. Others		
# of students	percentage	subtotal & total percentage
1	100%	
1	80%	subtotal= = 2 = 13%
1	25%	
1	5%	
1	1%	

[6] Only 15 of these 16 students specified precentage of their knowledge source.

Students' Difficulties in Learning the Effect of Evaporation And Condensation on the Surrounding Air

The following description is a summary of concepts with which students had difficulties in order to understand evaporation and condensation.

Heat transformation involved in evaporation and condensation. When water evaporates, it absorbs heat from the surrounding air. When water vapor condenses, it gives off heat to the surrounding air. Thirteen students (57%) were wrong on the question about heat transformation in evaporation and 11 (48%) were wrong for condensation. One of them, Judy, reported that evaporation and condensation were so close in her understanding that she could not distinguish them. Mary had asked a related question in class, had been interviewed three times on the concepts, and still made the same mistake on heat transformation. What is surprising is that these students felt moderately confident in their answers (on the average, 7 on a scale of 10).

Where energy comes from and transfers to. A related concept to heat transformation is where heat energy comes from and where it goes in the process of evaporation and condensation. In the class discussion of the first night, Mary's question indicated that she did know the necessity of heat absorption but did not know where the heat came from. She said, "when I think of vaporization, I'm always thinking it takes heat to do that, it's hot when it vaporizes." She did not know that water molecules absorb heat from the surrounding air, which cools off the surrounding air. Joan and Jeneen had the same difficulty. They knew that heat transformation must be involved since evaporation is a cooling process. However, they had no way to figure out the effect of evaporation and condensation because they did not perceive molecular movement as energy and relate them to change of states.

Molecular movement and energy. By definition, molecular movement is kinetic energy. In any state of water, molecules move constantly, in which energy resides. Mary, Joan, Jeneen, and Judy did not think of water vapor as molecules of vapor with rapid movement or with energy. Four of them had difficulty understanding the effect of the change of states. About 83% of the total students did not explain the effect of perspiration in terms of molecular movement in the essay on the second conceptual profile inventory.

The importance of integrating molecular movement, energy, and change of states. Students had more difficulty understanding the effect of condensation than evaporation. For example, Mary understood that evaporation is a cooling process by figuring out heat transformation between surrounding air and water, but she could not explain the effect of condensation. She thought that heat was used up for evaporation and could not be retrieved to warm up the adjacent air during condensation. The results of the second conceptual profile inventory also confirmed the oral reports from Mary, Joan, and Jeneen. About two times as many students made mistakes in terms of molecular movement concerning condensation than on molecular movement concerning evaporation.

Based on students' responses to the second conceptual profile inventory, 19 (83%) students answered correctly the true-ralse item, "the degree of the movement among molecules increases in the process of evaporation." Only four of these 19 students (21%) mentioned molecular movement in their answers to the essay question asking about the effect of perspiration on the body using the notion of heat exchange in molecular terms. One of these students, Caroline, did not specify where the energy comes from and what it is used for in her answer. In the essay, Caroline wrote, "When water molecules on your skin are broken away, heat energy is lost from your arm and goes into the vapor."

Eleven of those 13 students (85%) who had the concept of heat transformation wrong answered the essay question at a very superficial level. To provide a full explanation in response to the essay question, the following information is necessary: (a) perspiration absorbs heat from the body, (b) the increased heat energy speeds up the molecules' movement in the perspiration, (c) the heat energy is stored up to a point until evaporation occurs, (d) when perspiration evaporates, the heat energy goes with the vapor. Only 17%, 13%, 4%, and 17% of the total students mentioned each of these bits of information respectively. The main information students put down was that "perspiration helps to cool the body."

Hypotheses of reasons that hinder students from conceptualization.

If students memorize information presented in the textbook without understanding it, they may not internalize the concept Students sometimes just memorize concepts without really understanding them. When they are asked to explain, they can only repeat the information they read from textbook. They only have pieces of information and don't know how to integrate them to explain evaporation is a cooling process. Twenty one students (91%) answered one item, "The cooling effect from perspiration relates to evaporation," right, but only three students (13%) can explain it in their essays. They knew that "evaporation is a cooling process" from reading their textbook but did not know the reason for it. Mary had learned evaporation from her oceanography class the previous year. She memorized for the test and thought she had understood it, but she could not relate it to weather.

Students need to receive explanations that they can relate to in order to understand abstract concepts. Students often reported that they needed to be explained in order to understand abstract concepts. They could not understand from reading their textbook, especially when they did not have anything to relate to. The terms that the textbook authors used were "too technical" for students to understand. Joan reported that "I cannot just read it and understand it, I have to have someone talk to me and give examples." After her teacher's explanations, Joan understood. She reported, "He explained it better because he used more the terms that I can understand and he gave real examples."

Intuitive thought (or preconception) may interfere with conceptualization. Students often explained the world according to observable cues without verification. When they find their understanding conflicts with the scientific explanation, they almost need to fight against themselves in order to accommodate (You, 1992). Based on her own observations, Mary associated evaporation to steam and condensation to cold water, she said that "when I think of evaporation, I'm thinking of a hot steaming day where water is evaporated ... when it rains, it cools." She realized from class discussions that she concentrated on "temperature" rather than energy transformation, but she still kept thinking of "temperature." Judy had the same problem. When she thought of change of states, she intuitively related to temperature rather than molecular movement or energy transformation. Both of them needed to think very hard to correct themselves with many trials.

Interruptions interfere with conceptualization. Students sometimes feel that their comprehension of the teacher's response to their question is interfered with by their teacher's and classmates' interruptions (You, 1992). When Mary raised the question in the class, eight persons actively participated in the discussion. Mary had a hard time understanding others and being understood because of the interruptions. First simply stating her question took seven turns and the teacher misunderstood her question as "latent heat." People hardly expressed their thoughts fully in the discussion because of interruptions. Mary reported that "I just wish [everyone] let him have a floor and finish what he was going to say ... when they jumped in, it's confusing, and it made me loose my train of thought. I felt I was almost on the verge of understanding it and then it was kind of snap." Besides, Mary could not straight them out clearly when several perspectives were presented to her all at once.

Textbook and classroom discussion sometimes provide disconnected information that did not help students to understand abstract concepts. In order to understand why students did not understand from their readings, we analyze their textbook. Although, the author of their textbook did not explain evaporation and condensation from a basic level, he had all information students need to understand why evaporation as a cooling process. However, the author stated a critical information, "kinetic energy is the motion of its molecules" in the previous chapter. Besides, his explanations for where heat energy goes during evaporation did not come right after his explanations that the increased heat energy breaks water molecular bonds and causes evaporation. Since students did not have basic understanding of molecular movement and energy, they did not understand the effect of evaporation and condensation on the surrounding air just from reading. In addition, some students reported that they just read parts of the text that they were assigned for. The chapter that contains "kinetic energy is molecular movement" was not assigned by the teacher.

The discussion that Mary's question generated covered what latent heat of vaporization is, molecular movement, energy, change of states, energy transformation, and distinction between temperature and heat. They are all what students need to know in order to understand evaporation and condensation. However, this information is disconnected. Everyone gave bit and piece information in his or her own terms, not necessarily scientifically correct. Plus, no one could explain the concept completely without being interrupted. The talk that was given by the junior college physics teacher was maninly about how change of state does not require a change in temperature, which did not directly deal with the students' misconception and the critical information they needed, as mentioned above.

Students were sometimes not attentive to class discussions. Students were sometimes not attentive to class discussion. Kathy fell to sleep so she did not hear what the class talked about latent heat. Jim's explanations for heat transformation, energy, and change of states were very informative, but Cindy tuned off because she had always thought Jim just wanted to show off. Both Joan and Jeneen thought Jim "used too big a word" and "just confused" them. Jeneen wished Jim shut out so that she could listen to the teacher's explanation.

Conclusions

Our findings indicate the importance of identifying students' preconception about concepts. They also point to suggestions for effective classroom discourse: (1) explain new concepts to students in a simple, well sequenced, organized way and without interruptions, (2) help student integrate their knowledge (students tend to own pieces of factual knowledge and don't know how to integrate them to interpret the world), and (3) help student become aware of the importance of their classmates' contribution to their own understanding.

APPENDIX 1: LECTURE TRANSCRIPT IN EARTH SCIENCE CLASS ON APRIL 10, 1991

H "... and it's appropriate now to pass out this question." [for weather station exercise]

Mary "May I ask a question?"

H "You bet."

M "I do not understand latent heat of vaporization."

H "The rate?"

M "Latent heat, the latent heat."

H "Oh, latent heat, all right, just, hang on, and I'll attend to that. (6.5) [put away the exercise sheet] Let's go back to that, Mary. What page was that on?"

M "That is on 398."

H "388?"

M "398. I understand"//

H "Need to] check my hearing, too."

M "I understand when it goes from liquid to vapor requires heat to do that, but, I don't understand what the"//

H "The word latent"]

M "effect] on the air around it. (5.2) If it's absorbing the heat to make, to become vapor"//

H "It's, it's] amount of something waiting to happen. That's what the word, latent, means. The latent heat of vaporization means the amount of heat necessarily to convert the water to a vapor. It's, it's the heat waiting to happen. I, I, um, that maybe not be a good definition, um, in terms of physical science, but I'd like to think of it that way because it's, it's like the difference between kinetic and potential energy for me. Kinetic is working energy, is doing something; potential is latent, is waiting there. It, it has the ability to produce motion or whatever else is going to produce. Latent heat, to me, is that kind of heat. Now, does someone else have a, is that of any help to you, //or"

M "No."]

H "is that not getting to the point?"

M "No."

H "All right."

Roger "Evapo-rization is a cooling process. And, heat is stored in the, in the"//

M "I guess like you're saying"]

R "water mole-] kinetic energy and water molecules in the back. They're moving around, right, they're spreading out, water molecules are, when it becomes water vapors. So, the kinetic energy stores there. When it rains" =

H = "It stores its potential energy// yeah."

R "The latent heat] and the latent, the latent heat of rain, will be the heat that is released when it condenses and falls back to earth."

Jim "It's latent heat of condensation." ((softly))

H "Because of any time motion occurs, any time something happens, heat is released."//

Jim " (con-)"]

H "Uh, (2.5) it's, it's the heat in your food, that is, you take a bite of a carrot. Obviously, most of us eat cold carrots. Let's to say, pretend we take, there's a lot of heat stored in that carrot, that is, as soon as it changes forms by digestion and gets to your blood stream, it's oxided or burnt, that heat escapes, uh." =

Nanny = "Yeah. ( )"//

Jim " ( )"]

M // "I think what I have been confused is] that you said evaporation"

Jim //"OK."

M "is] a cooling process"=

R = "Right." =

M = "And when I think of vaporiza-tion, when I think of that, I'm always thinking it takes heat to do that, it's hot when it vaporizes."

H, J & R "Umhm, umhm." [indicate "no"]

M "See, that's where I'm getting //confused."

H "It has a] // potential for being hot"

J "That was ( ) put heat away"]

H "but it isn't until vaporization occur or the actual molecules get together and do their things that, then heat is given up. Nanny, how do you deal with this with six graders, do you?"

N [shake her head]

H "Peter,"

Students // (h)

H "you've ever dealt] with it?" =

Caroline ="Kids, (kids a wet) shirts on a line in Alaska where is so cold, dry by this //and there's no heat."

Jim "By latent heat of that"] ((softly))

C "But the latent heat (gets in there.)" =

Jim = "vaporization." ((softly))

H "Yeah, changes, they just become dry without"//

C "It's not heat it's just]

H "without heat."

J //"Temperature involves ( )"

H "But, I understand] her problem. She, this is, again for those of you teaching, most of us, this is a formal operational level of thinking. This is requiring abstract, symbolic logic to understand this. For me, I'm picturing this in my mind. I'm like an Eskimo." =

R = (h)

H "Eskimo, Eskimo would say you talk about tracking last week. Eskimo says "I see the man running in my mind." You know, they put it in present tense. When I hear this description, I've given, that Roger gave. I hear, I see a, I form a picture of it happen now in mind as a diagram. I can't visualize any other way. So, I tend to explain it that way. You still don't get it, do you?"

M "Not, not a hundred percent clear, but (I'll get that later.")

H "We have a physics persons in here, is it? Joan, can you?"

Joan (h) ("Do you")

H "Not, but I watching you use your hand to talk to Anita and I" =

Joan = "I remember drawing a chart about how it" //

Jim "That's the plat-"] ((softly))

Joan "goes from ice cube and use the latent heat and it goes to water."

H "But what did you," //

Jim "That's a plateau, that's the ( )"]

H "what did you mean that use the //latent heat?"

Dorothy "Isn't the molecule] bouncing to each other and it gives off heat?"

H "I know that." =

D = "But I mean, I'm, and if it's not"//

Jim "That's"] ((softly))

D "If the molecule aren't changed, and they're just sitting there, and then they're going to have latent heat. And if they're change, you know, they start to bounce around and they're going to give off heat."

H "Put your two hands together, Mary. Do they feel hot?"

M "No, I'm cold right now." (h)

Students (h)

H "OK. Alright, do this, rub them together like that. [H is rubbing his hands]

M "OK, ok, yeah, I felt heat."

H "OK, where does that heat come from?"

M "Is that latent heat?"

Students (h)

H (3.5) "Your hands."//

Myra "It's friction."

H "I know] that's friction, I know // but"

Jim "I'm being good."] ((softly))

H "Your hands have the ability to produce heat. Right now, when you touch them together, there's not heat there." =

M = "But, the potential is what you called it the latent heat."

H "Yeah, there were produced due to friction but latent heat is stored. It's a potential"//

M "OK."]

H "physical"

M "OK, //I understand that."

H "ability] of a substance to give off heat once it's moti-vated into move. Jim, how, would you?"

Jim //"I tried not to"

Nanny "Oh, is there a] distinction here between. I noticed, Jim, a while ago, you made a distinction between heat and energy, (it's //instance) oh,"

Jim "It doesn't."]

N "made the distinction for me."

Jim "If we think of, what it is we tried to do? We have a liquid. We're going to a gas, gas turns to vaporness in this case. If I want to do that, I have to put energy into it. I can put energy into it more and more and more, I'll get to a point at which it has as much energy as possible as a liquid. In order to keep that energy." =

H = "Now, wait, how do you get to the point where it// has as much" =

Jim = "I'm trying to] avoid getting into"

H //"I know."

Jim "heat] versus temperature and things like that." =

Mary = "See, I think that's what I'm confused. I think of heat as temperature."

Jim "OK."

M "And I need to think of it as" =

H = //"Temperature as a measurement of"

M "a measure of"] =

Jim = "The average amount of kinetic energy."

M "OK."

Jim "OK, kinetic energy would be the movement of the molecules. What I'm going to do is put heat into it. I'm going to put energy into it in the form of making those molecules move faster or vibrate faster."

Nanny "OK, you just went back to latent heat and energy."

J "That's because"//

H "Yeah."] //

Roger (h)]

Jim "he said go back to it."

N "Oh.// OK."

H "It's] very difficult // to ( )"

Jim You, you] have to distinguish between heat and temperature. Temperature is just average movement of those molecules. Once I have a certain amount of heat in that, at a certain point [Dr. H is passing out the weather station exercise at this moment] that can no longer contain that heat, if you will, in that state. In order to maintain that amount of energy, it has to go to a gas, as gas has that energy now, that was the latent heat of vaporization. OK, so if you can picture these molecules moving around, then it got all loose changes with its energy, if you will. If you want to go back to a liquid, the form of va-, of condensation, it has to get rid of that changes, OK."

Mary //"OK."

Jim "So //it's the same"

H "But, see,] that's an anthropomorphic kind of." =

Jim = "Well, I'm trying to put in terms of, you may want to explain to a kid.// I mean, I can see they talk about to that energy."

H "Yeah, but you can't do it.] You can't do this of its own (volition.)"

Jim "No."

H "This is related, very directly related to the, to other factors going on around in the environment, such as the temperature in the air."

Jim "Well."

H "The relative humidity." =

Jim = "Specific] heat of the object." =

H = "Specific heat of the object. And, it isn't easy to explain some of this."

Jim "It's hard to explain in very simplistic term. I mean, that's about the way I would explain to my 8-grade kids, and" =

H = "But, what you hope is they don't ask that question, Mary."

Jim "And they will ask that question.// They sure will."

H "I know] they will."

Mary // "(research)"

H "You should be getting,] you should be getting three different sheets of paper. One of these looks like this on which you will put your name. One of these looks like this on which you'll receive a lot of data [passing out the third sheet] (19.1) And, one looks like this, with six empty squares, (5.1) Mary, I'll see this week if I can obtain a better definition of latent heat for you related to this, from, um, someone in Physics that communicate well to nonphysics people, I'll see what I can do."

Jim "They don't, they typically just skip that term entirely."

H "Yeah."

Jim "They don't talk about latent heat."

H "I'll just see what we can do."

Caroline "We talked a lot in oceanography, I think, if I //read my"

H "Oh, late."]

C "notes from that class I can understand that again"//

H "Sure."]

C "We did experiments and stuffs when we talk about a lot //how it, it stops and"

H "Oh, I think it's."]

C "You couldn't see everything for a while and that// was because"

Jim "That was the plateau."]

Mary "See, I understood that. It's just with this temperature ( )"

C "But this is the same thing."

M "Well, ( )"

H "( ) I understand your point. I really do. I'll see if I can get a better explanation or one is more clear for you. At this time, I'm going to skip the, uh, sling psychrometer activity for today. I <u>will</u> come back to that."

APPENDIX 2: TRANSCRIPT NOTATIONS

( )	empty parentheses or parentheses surrounding a word indicate uncertainty about transcription.
(1.2)	parentheses around a number on a line or between lines indicates silence, in tenths of a second; only silences greater thanone second, are indicated by numerical value.
...	ellipses indicates silence of less than one second.
//	double slashes indicate the onset of overlap.
]	right brackets indicate the end of overlap.
=	equal signs come in pairs, at the end of one line or utterance, and at the start of a subsequent one; the talked linked by equal signs (whether different speaker or same speaker) is continuous, and is not interrupted by any silence or other break.
? . ,	punctuation marks indicate intonation contours; they do not indicate grammatical status; question mark indicated upward intonation; period, downward intonation; comma, continuing intonation.
wor-	the hyphen indicated the self-interruption or cut-off of the preceding sound.
ran	underlining indicates emphasis.
ACT	upper cap indicates marked increase in volume.
(h)	the letter "h" surrounded by parentheses indicates laughter.
((softly))	words surrounded by double parentheses indicate transcribers characterization of the talk.
[pointing]	words surrounded by brackets indicate some non-verbal action of the participants; such actions are noted only in instance when transcriber could confirm such actions through reports of the participants.

The notational conventions employed in the transcripts are adapted and modified from the following: Schegloff, E. A. (1987). Analyzing single episodes of interaction: An exercise in conversation analysis. Social Psychology Quarterly, 50(2), 101-114 cited by Saunders, Goldenberg, & Hamann (1991).

APPENDIX 3: CONCEPTUAL PROFILE INVENTORY I

I'm interested in knowing how you learned about "latent heat." I have listed some possible sources below for you. Please specify what percentage of each source contributed to your understanding of "latent heat" before today's class.

______ 1. from classes that I took previously
(when ________ class ________________________)
______ 2. from reading the textbook for this Earth Science class
______ 3. from class discussion of last Wednesday (April 10th)
______ 4. others (please specify them ________________________)

If your understanding of "latent heat" changed as a result of last Wednesday's discussion, please specify how it changed.

____

____

____

How does "latent heat" relate to meteorology?

____

____

____

What were the new insight(s) you gained from today's lecture that added to your knowledge of "latent heat," if any?

____

____

____

APPENDIX 4: CONCEPTUAL PROFILE INVENTORY II

For each of the following statement select true or false and then immediately rate how confident you are of your choice on the scale following the question.

T F (1). When water evaporates, it gives off heat to the surrounding air.

10 9 8 7 6 5 4 3 2 1

T F (2). When water evaporates, it absorbs heat from the surrounding air.

10 9 8 7 6 5 4 3 2 1

T F (3). When water evaporates, the heat exchange between it and surrounding enviornment is not involved.

10 9 8 7 6 5 4 3 2 1

T F (4). In the process of evaporation, the degree of the movement (vibration) among molecules increases.

10 9 8 7 6 5 4 3 2 1

T F (5). In the process of evaporation, the degree of the movement (vibration) among molecules decreases.

10 9 8 7 6 5 4 3 2 1

T F (6). In the process of evaporation, the degree of the movement (vibration) among molecules remains constant.

10 9 8 7 6 5 4 3 2 1

T F (7). When vapor condenses, it gives off heat to the surrounding environment.

10 9 8 7 6 5 4 3 2 1

T F (8). When vapor condenses, it absorbs heat from the surrounding environment.

10	9	8	7	6	5	4	3	2	1

T F (9). When vapor condenses, the heat exchange between it and surrounding environment is not involved.

10	9	8	7	6	5	4	3	2	1

T F (10). In the process of condensation, the degree of the movement (vibration) among molecules increases.

10	9	8	7	6	5	4	3	2	1

T F (11). In the process of condensation, the degree of the movement (vibration) among molecules decreases.

10	9	8	7	6	5	4	3	2	1

T F (12). In the process of condensation, the degree of the movement (vibration) among molecules remains constant.

10	9	8	7	6	5	4	3	2	1

T F (13). The cooling effect from perspiration relates to evaporation

10	9	8	7	6	5	4	3	2	1

T F (14). The cooling effect from perspiration relates to condensation

10	9	8	7	6	5	4	3	2	1

T **F** (15). The warming effect from perspiration relates to evaporation

10 9 8 7 6 5 4 3 2 1

T **F** (16). The warming effect from perspiration relates to condensation

10 9 8 7 6 5 4 3 2 1

(17) Use the notion of molecular vibration to explain the effect of perspiration on the body?

APPENDIX 5: INFORMATION FOR THE TARGET CONCEPT IN THE TEXTBOOK

The evaporation of water vapor from bodies of liquid water and the sublimation of water vapor from ice require that water molecules break away from their neighbors and enter the overlying atmosphere. This breaking of the adhesion that holds water molecules together requires an expenditure of heat energy, which is taken from the adjacent environment. Evaporation, therefore, is a cooling process. We recognize the cooling effect of evaporation whenever wind blows over skin that is moist with perspiration. The heat absorbed by water molecules during evaporation is one reason why the temperature of the ocean rises so little, even when bathed in the sun's rays. An enormous amount of the energy in those rays is utilized in evaporation, rather than in heating the ocean. Another example of the cooling effect of evaporation is experienced when temperatures drop after a summer shower. The air becomes cooler partly because of the heat extracted from it by evaporation of falling rain.

The heat needed to convert liquid water to water vapor is called latent heat of vaporization. The term "latent" conveys the notion that the heat has accompanied the departing water molecules during evaporation and resides within them during the vapor phase. During subsequent condensation, the latent heat is released into the environment as heat, warming the air around us. (Levin, p. 398)

APPENDIX 6: TRANSCRIPTS OF MARY'S REPORT ON APRIL 29, 1991

Listen to Jim's "So, to that would be if I have water is a liquid. In order to get it changed to a gas, into vapor, I have to add energy, a form of heat that causes the water molecules to vibrate or move faster. They now a gas, if I want them to go back to a liquid, they have to loose that energy or that heat. Where is that heat? Where that energy go? They went into the air. That's what happens to the air around the water." (4/18/Jim/232-8)

LC: "I'm wondering by now what this trigger you to relate to your question."

Mary: "That he just gave me, well, um, they deal directly with the question, but I still don't have it 100% clear in my own mind."

LC: "What is the fuzzy part?"

Mary: "He said, you know, that if you're using up the energy, you're using energy to convert from liquid to vapor. I understand that. And then, I think, you know, when you're using it, it's gone, (it's like) burning firework. You burn it, it's gone. This change state say yes and, you see what I'm saying, like you use gas in your car. When it's on empty, it's empty; it's gone. It's not (reserve) some place else to where you can retrieve it and use it again. And, like I said it's what I have problem with. It's when I'm told something is gone, that's it. It's dismissed from my mind. And I don't think that will be retrieved later."

LC: "When you said 'it's gone' means that the energy is gone."

Mary: "The energy is gone, I would think. I'd think it's been used up. It's changing the state.

LC: "How about."

Mary: "It's real complex."

LC: "It is."

Mary: "Um, ( ) for me to under, to understand and I have the same problems with astronomy, um, with the two chapters that going now. I mean a lot of it I can't visualize it. If they can show a, um, a mode of it, then I can grasp it, but I really have to think long and hard and read it, reread it, and reread it. Try and visualize. I'm a very visual, hand-on person. I have to visualize it before I really truly understand it; and can keep it up here and explain to somebody else. And, I get frustrated when I don't understand it and ( ) I just don't even care about it. And, I'm just sitting there (burn it) (h) ( ) forty years ( ) (it doesn't matter.") (h)

LC: "How about this. Let me replay it."

Listen to Jim's "where does that energy go" (4/18/Jim/237)

LC: "He said that "where does that energy go."

Mary: "The energy go, he says it went into the atmosphere."

LC: "So, it does not disappear."

Mary: "Right."

LC: "It goes to the //environment."

Mary: "Well,] but it has a, yeah, it's going to environment, but at a different portion of the environment. So, I can see where it's cooling off the land. It's going into the air. I was thinking (some of the air.) You see what I'm saying, that heat, that heat energy."

LC: "Are you talking about evaporation?"

Mary: "Uhmm, evaporation, right."

LC: "So you think that, does evaporation take off the energy, needs the energy to make it evaporate."

Mary: "Yeah, it sounds me that he's saying, you have to use; you want to change state. So, he says, ok, let's give some heat energy to the water, to change states, alright. And then when you're, when it changes state, it sounds like it just keeps that energy with it, takes that with it and I guess."

LC: "What is the energy used for?"

Mary: "I guess it's just blowing around some places with the vapor. See, it's so abstract. I had, I had a real hard time grasping it."

LC: "Yeah, if we were thinking in terms of molecular terms. OK."

Mary: "Uhmn."

LC: "So, the water takes the energy, takes energy. And then how is energy going to help or influence the movement among the molecules."

Mary: "It helps move more rapidly."

LC: "Yeah, move more rapidly."

Mary: "Yeah, so they can change state."

LC: "So, since we absorb the heat from the atmosphere and make them move faster. So, what is the effect on the surrounding air then?"

Mary: "That it would be cooler."

LC: "Why is it cooler?"

Mary: "Well, I guess cooler on the surrounding air. [rasing up voice] Well, see, that's where I'm confused. I don't think it makes the water or, well (4.6) whatever contain the water, whatever the water was on, I'd think the surface of that would be cooler, but I wouldn't really think the air around you will be cooler because that heat energy is been absorbing into the air."

LC: "So, you're saying that the inference on the, the impact on the surrounding air won't be that large."

Mary: Right."

LC: "Would be //just."

Mary: "Right.]

LC: "Very little."

Mary: "Very little."

LC: "That makes sense, um."

Mary: "He just better not asking on the test."

LC: "No."

Mary: (h)

LC: "You can be sure, he hates it."

Mary: "He won't ask it, hl (h)."

LC: "It's me. I'm just interested to know what's going on. Uh, this is another information from Jim talking about rain that you're interested to know."

Listen to Jim's "What makes it rain. Well, when we lose that energy, well, what do you mean "lose it." Where did it go? Well, it went into the surrounding air. So, actually the air temperature warms up" 4/18/Jim/294-6

Mary: "OK."

Listen to Jim's "the rain droplet" (4/18/Jim/237)

LC: "Uh, what does that makes sense to you?"

Mary: "Well, the air is warming up. And, so, as the air warms up, it can hold more moisture. And it, um, it, it reduces the air pressure so that all this vapor can go up. Ad then, if it gets up the cooler air will condense. That's going to cause precipitation. So, I understand that. So, that would be ( ) relate to weather."

LC: "Yeah, it is."

APPENDIX 7: THE EFFECT OF EVAPORATION AND CONDENSATION ON THE SURROUNDING AIR: KINETIC ENERGY, MOLECULAR MOVEMENT, AND CHANGE OF STATE

There are three states of matter, solid, liquid, and gas. Molecules of liquid water are attracted to one another and are in a constant movement. The movement of molecules is a form of energy called kinetic energy. The faster the molecules move, the more kinetic energy they have. When heat in the adjacent environment is higher than that in liquid water, heat exchange occurs. The increased heat energy then causes the water molecules to move faster. As the water molecules continue to vibrate faster and faster, it builds up kinetic energy. The temperature of the water rises to 100 degrees Celsius. Then it stops rising. As more heat is absorbed, the molecular movement does not increase. Instead the molecules overcome the force that holds them together in the form of a liquid. The molecules move further apart and the liquid changes state to become a vapor. This is called evaporation. The temperature at which this occurs is called the boiling point. Both liquid and gas exist at this same temperature. The amount of heat energy needed to convert liquid water to water vapor is called latent heat of vaporization. Because heat in the adjacent environment is used to vaporize water, it "cools off" the surrounding air.

Molecules in water vapor move around freely and rapidly. When heat in the adjacent environment is lower than that of the water vapor, heat exchange occurs. The heat energy is transferred from the water vapor molecules to the surrounding environment. The decreased heat causes the water vapor molecules to move slower. The water molecules continue to vibrate slower and slower due to the release of kinetic energy. When enough energy has been transferred to the adjacent environment, the water vapor will become a liquid. This is called condensation. Because heat energy is transferred to the adjacent environment from the water vapor , the environment "warms up."

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